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## An Overview of Methods and Key Findings

M. JOURNEAY, JZK. YIP,  
C.L. WAGNER, P. LESUEUR AND T. HOBBS

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**Authors:** M. Journeay<sup>1</sup>, JZK. Yip<sup>2</sup>, C.L. Wagner<sup>1</sup>, P. LeSueur<sup>1</sup> and T. Hobbs<sup>1</sup>

<sup>1</sup> Geological Survey of Canada, 1500-605 Robson Street, Vancouver, British Columbia. V6B 5J3

<sup>1</sup> Technical Safety BC, Suite 600 – 2889, East 12th Avenue, Vancouver, British Columbia. V5M 4T5

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## INTRODUCTION

While we are exposed to the physical effects of natural hazard processes in a similar way, certain groups within a community often bear a disproportionate share of the negative impacts and related socioeconomic consequences when a disaster strikes. Lower-income households, recent immigrants, racially marginalized populations, and other groups whose rights and needs are not always fully considered in the context of community planning or disaster risk management are most often the ones who are encumbered with more limited access to support networks and the resources are needed to weather unexpected disaster events. (Blaikie et al., 1994; Comfort et al., 1999; Petterson 1999; Godschalk 2003; Andrews and Caron 2016; Sarmiento et al., 2020). Differential capacities to withstand and cope with the immediate health impacts and downstream socioeconomic consequences of the recent COVID-19 pandemic have highlighted systemic patterns of social vulnerability that exist at the community level here in Canada (Mo et al., 2020; Statistics Canada 2022). Understanding these disparities as the outcome of underlying social, economic, and political factors that have influenced patterns of development within a community or region is an important step in identifying and prioritizing actions that can be taken in advance to reduce intrinsic social vulnerabilities and to enhance the prospects of longer-term disaster resilience.

This overview document provides a synopsis of analytic methods and results for a national model (CanSVM) developed by Natural Resources Canada to assess intrinsic social vulnerabilities to natural hazard threats at the community level in Canada (Journeay et al., 2022, work in progress). Model outputs provide insights on *why* some places and population groups are more vulnerable to natural hazards than others; *who* is most likely to bear the greatest burden of risk within a given community or region; and *what* are the underlying factors that disproportionately affect the capacities of individuals and groups to withstand, cope with, and recover from the impacts and downstream consequences of a disaster. Our work builds on and complements other similar assessments of social vulnerability that have been undertaken to evaluate systemic issues of inequity and marginalization from the perspective of human ecology and environmental justice (Matheson et al., 2012; O'Sullivan 2013; Auditor General of Canada 2018; Chang et al., 2018; Indigenous Services Canada 2019; Statistics Canada 2019; Chakraborty et al., 2021). Figure 1 summarizes key elements of the model design and workflow.

Methods that are specific to the requirements of this study include (i) assessing dimensions of social vulnerability in the context of land use and development patterns related to different types of settlement (i.e., metropolitan, rural, and remote); (ii) using context-specific thresholds of exceedance to measure characteristic patterns of vulnerability across multiple scales of aggregation, and; (iii) evaluating levels of disparity in the context of land tenure and related levels of access to essential services that affect overall capacities to withstand and cope with disasters. Profiles of social vulnerability are assessed at the dissemination area level for all settled areas in Canada using a framework of indicators derived from demographic information compiled as part of the 2016 national census. Model results are incorporated into an integrated assessment to evaluate the combined social and physical determinants of earthquake-related hazard threats (e.g., ground shaking and tsunami inundation), and the implications for disaster risk management at the community level. Although focused on seismic hazards, the underlying analytic framework is designed to accommodate other hazard threats of concern and has been successfully tested using results of a national-level assessment of earthquakes, tsunamis, floods, hurricanes, wildfire, and landslides in Canada (Journeay et al., 2022, work in progress).

The overarching goal of this work is to raise awareness and understanding of the social determinants of risk and how this information can be used in practice to inform actionable disaster risk reduction strategies at local and regional scales in Canada. Primary end users are likely to include emergency management practitioners responsible for addressing the impacts of future hazard events during immediate and sustained response stages of disaster recovery, and community planners who may need additional information to undertake an integrated HVRA to inform policies that enhance both overall disaster resilience and the prospects for sustainable development. Model outputs are accessible through an open-science data platform designed to support disaster resilience planning in Canada (Natural Resources Canada 2021).

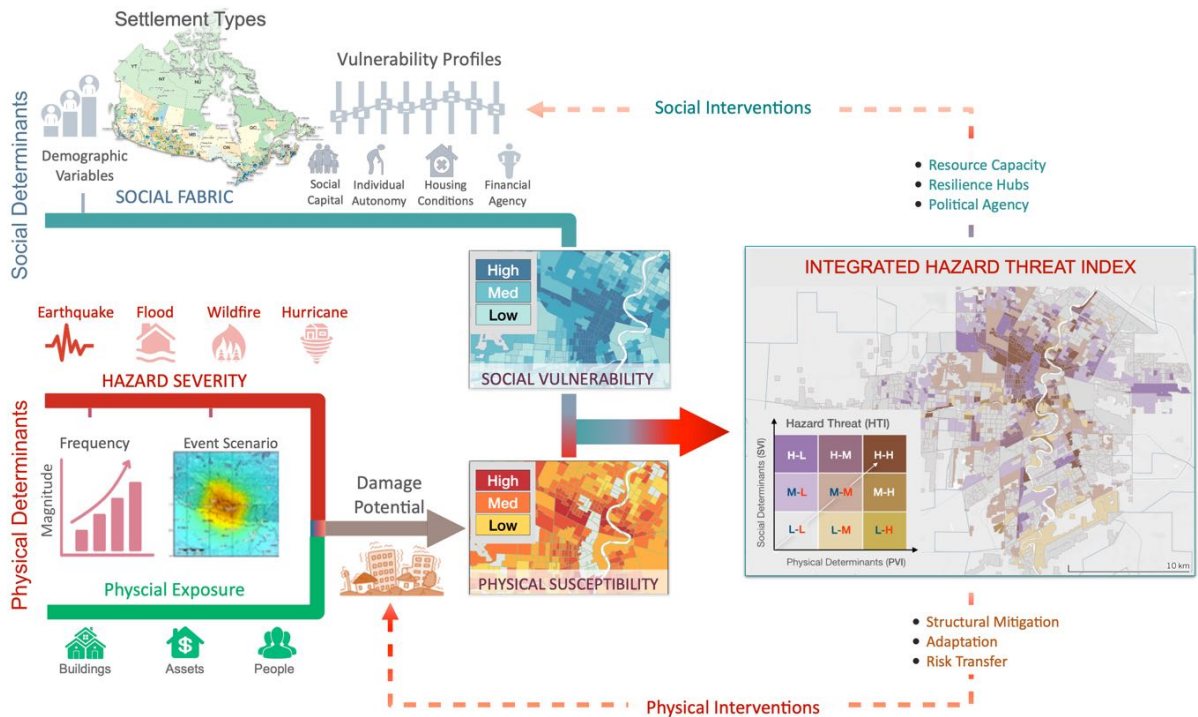


Figure 1: Summary of analytic workflow used to develop the national social vulnerability model for Canada.

## MEASURING SOCIAL VULNERABILITY TO NATURAL HAZARDS

Social fabric describes the demographic characteristics of people living within a neighbourhood or region and their relative capacities to weather the sudden shocks of hazard events that can disrupt the normal routines of day-to-day life. Social vulnerability focuses on the underlying characteristics of social systems existing prior to a disaster event that can predetermine differential levels of access to resources and services needed to support the day-to-day activities of residents and businesses, and the degree to which members of a community may suffer harm as a result (Cutter 2001; Wisner 2004; Birkmann 2006). Resilience refers to the inherent capabilities of these same social systems to take actions in advance of or following a disaster event that increase levels of safety, security and the prospects of functional recovery for all members of a community or region (Folke et al., 2002; Adger et al., 2005; Walker et al., 2006).

Our assessment of social vulnerability is based on the Hazards of Place' model, which considers both the underlying social determinants of vulnerability and corresponding physical characteristics of exposure and susceptibility to natural hazard threats that are specific to a particular geographic setting (Hewitt and Burton 1971; Cutter 1996). A distinguishing characteristic of this model is a focus on the spatial interactions between social, economic, and physical dimensions of vulnerability that vary over time – and that are manifest in different ways at the scale of a given community or region. System interactions are evaluated using a blend of statistical analysis and geospatial modeling to assess how patterns of vulnerability vary from one place to another as a function of (i) social inequities that are intrinsic to a particular community or region; (ii) levels of physical exposure and susceptibility to natural hazards that are controlled by geographic setting, and; (iii) human adjustment behaviors that have a potential to either amplify or lessen the outcomes of disaster events over time. The modeling framework is used to assess integrated physical and socioeconomic threats associated with earthquake and tsunami hazards, but can be implemented in the context of other hazards of concern and at variable scales of analysis.

## Model Design and Structure

The national CanSVM model is framed in the context of specific settlement types that reflect underlying characteristics of the built environment (e.g., density, land use, tenure, and governance), and the hierarchical arrangement of complex social, economic, and political systems that have shaped fundamental patterns of development over time. Settlement types are defined based on a statistical area classification (SAC) that groups census subdivisions according to population density and whether they are part of a broader census metropolitan area, a census agglomeration, or distributed within less dense rural or remote settings with variable degrees of metropolitan influence (Statistics Canada 2016b). As shown in Figure 2, these include dense **urban centres** (SAC-1) and surrounding **suburban/exurban neighbourhoods** that occur in larger metropolitan regions (SAC-2,3); **rural hinterland communities** of variable size and degree of metropolitan influence (SAC-4,5,6); and more **remote settlements** that are situated along isolated coastlines and/or within sparsely populated regions of Canada's far north (SAC-7,8).

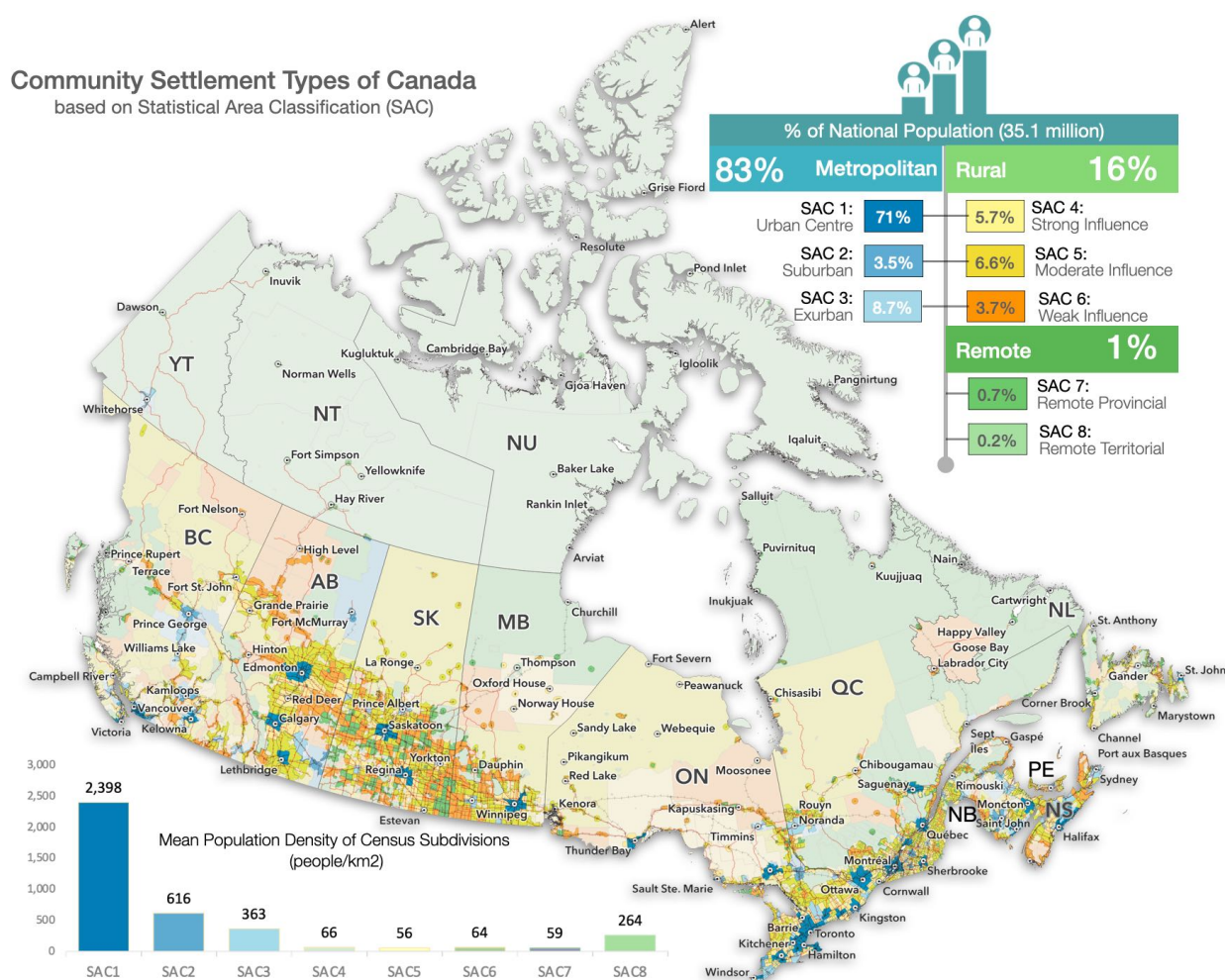


Figure 2: Community settlement types derived from a statistical area classification (SAC; Statistics Canada, 2016b) that reflects intrinsic characteristics of the built environment (density, land use, tenure, governance) known to influence patterns of social vulnerability.

Acknowledging the relationships between broad patterns of land use and the corresponding socioeconomic characteristics of population groups that have evolved as part of the development process provides the necessary foundation for evaluating underlying dimensions of social vulnerability that are specific to a given neighbourhood or place (Blaikie et al., 1994; Burby 1998; Mileti 1999; Mileti and Gailus 2005). This is particularly

important in large and sparsely populated countries like Canada where fundamental patterns of settlement can vary considerably from place to place as a function of geography, the dynamics of population growth, land management practices, and differential access to basic lifeline services. Each of these variables can influence the intrinsic capabilities of people to both withstand and recover from the impacts of a disaster event. For example, we know that people living in remote regions of Canada are generally more independent and resilient to change, but also more likely to experience poor health, unmet medical needs, and lower life expectancy as a result of limited access to lifeline services (Canadian Institute for Health Information (CIHI) 2012; Subedi et al., 2019). In contrast, metropolitan regions are characterized by dense urban neighbourhoods with mixed populations of different racial, cultural, and ethnic backgrounds who have more ready access to basic lifeline services, but who are also more likely to experience deep-rooted patterns of social inequity, displacement, and exclusion from wealth-generating opportunities (Blaikie et al., 1994; Comfort et al., 1999; Cutter et al., 2003; Pelling 2003; Wisner 2003; Batty 2013). Intrinsic patterns of social inequity in larger cities are amplified by development pressures associated with continued population growth and densification that vary in both complexity and levels of intensity from one region to another. While there is diversity in the fundamental characteristics of social fabric across different types of communities, it is the mix of demographic variables, and their relative degree of influence, that ultimately shape patterns of vulnerability within any given community. Demographic variables such as age, family structure, and cultural identity that may limit the capacities of those living in high-density urban neighbourhoods to manage sudden disruptions caused by a hazard event are, in many cases, the same attributes that promote resilience and adaptability among those living in more rural and remote settings (Cutter et al., 2016).

### Analytic Methods

Unlike physical measures of exposure and susceptibility to natural hazards, indicators of social vulnerability are based on proxy variables that represent complex and intangible interactions that occur between social, economic, and political systems over time. Indicators used in our assessment of social vulnerability are derived from available population, demographic, and housing information compiled at the dissemination area level as part of the national census (Statistics Canada 2016a). Our selection of vulnerability metrics is based on the results of comparable studies that have implemented the Hazards of Place model in a North American context (Hewitt and Burton 1971; Blaikie et al., 1994; Morrow 1999; Cutter 2001; Cutter et al., 2003; Cutter et al., 2008). Methods of Principal Component Analysis (PCA) are used to reduce a candidate list of 49 variables to a smaller and more coherent set of ~20 indicators that collectively account for characteristic patterns of variability within the broader set of demographic variables at a national scale. Attribute values are then normalized into a common range of between 0 and 1 using a MIN-MAX transformation where a score of 0.0 indicates the lowest value of vulnerability and a score of 1.0 indicates the highest value.

Statistical profiles of vulnerability are assessed with respect to patterns that are specific to a given settlement type (e.g., urban, suburban, exurban, rural, remote). Indicator values at a given location that are above expected mean values for a specific settlement type reflect conditions in which there are likely to be reduced capacities for community members to withstand and recover from a disaster event while those that are below these characteristic values reflect increased levels of neighbourhood resilience. This place-based approach is particularly effective in highlighting characteristics of social vulnerability that are specific to a particular type of neighbourhood and allows a comparison of vulnerability profiles from one region to another at a national scale.

As illustrated in Figure 3, profiles of social vulnerability are evaluated using a hierarchical framework of representative indicators that measure both absolute levels of disparity for specific settlement types at a given location, and the relative contributions of cumulative factors that are known to influence the capacities of community members to withstand, cope with, and recover from disaster events. These include family structure and level of community connectedness (social capital); the ability of individuals and groups to take actions on their own to manage the outcomes of unexpected hazard events (autonomy); shelter conditions that will influence the relative degree of household displacement and reliance on emergency services (housing); and the economic means to sustain the requirements of day-to-day living (e.g., shelter, food, water, basic services) during periods of disruption that can affect employment and other sources of income (financial agency).



Arranging indicators within a hierarchical model structure enables the aggregation of vulnerability metrics to identify hotspot areas of concern, while still preserving the ability to interrogate more detailed model results at a given location to determine which underlying factors may have the greatest influence on capacities for both disaster response and recovery. Indicators can be weighted based on input provided by domain experts who are familiar with the more specific vulnerability characteristics of population groups within a particular community and/or region (Oulahen et al., 2015). These additional measures increase both transparency and usability of the assessment framework by allowing the interrogation of individual indicator values within a particular dimension of vulnerability, and a comparison of performance measures across all thematic dimensions. More importantly, a focus on relative versus absolute measures is more likely to encourage an exploration of why some places and population groups are more vulnerable than others, as well as the identification of strategies that might be considered to inform disaster resilience planning at a community level.

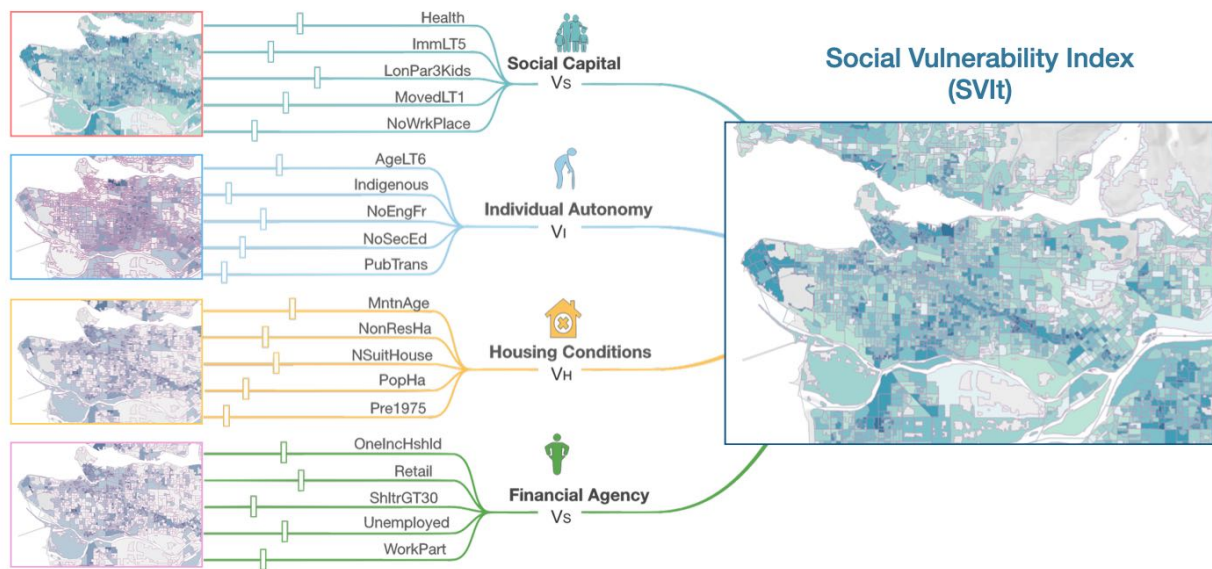


Figure 3: Hierarchical framework of indicators used to evaluate underlying factors that contribute to conditions of social vulnerability within a given neighbourhood.

To facilitate the interpretation of model outputs, we transform indicator values from absolute MIN-MAX values (e.g., 0.342) to a relative vulnerability threshold score by comparing measured values at a given location against characteristic or average values for a given settlement type. A score of +1 is assigned when an indicator value exceeds a mean value plus one standard deviation, while those that fall below these threshold values are assigned a score of 0. This process results in four distinct measures of relative vulnerability that can then be aggregated into a composite social vulnerability index score (SVI). The methodology allows for the assessment of social vulnerability at any geographic scale of interest by dividing the overall threshold score for a given level of aggregation and settlement type by the total number of unique locations. In these cases, the relative degree of vulnerability across communities of the same settlement type would be evaluated by dividing the aggregate threshold score for a given community by the corresponding number of unique locations sampled. This preserves the overall scale range of the social vulnerability index ( $0 < SVI < 20$ ) and facilitates the interpretation of regional patterns at variable scales of resolution.

A consequence of our model design choice is that absolute measures of social vulnerability can only meaningfully be compared between developed areas that are part of the same broad settlement type. For example, areas with anomalously high vulnerability threshold scores that occur in dense urban neighbourhoods of a major city cannot be directly compared with equivalent levels of vulnerability that occur in rural hinterland or remote communities. This is because the associated social vulnerability indicators are calibrated with respect to the distribution of values that are characteristic of a given settlement type, not a particular community or region.



The alternative is to reference indicator values with respect to mean values for all neighbourhood types within a given region. While this approach can be useful when comparing absolute measures of vulnerability from one place to another, it can also obscure intrinsic patterns of disparity and underlying factors that are specific to a given type of neighbourhood. As a result, we recommend that outputs of the CanSVM model be used to assess relative patterns within broad settlement types (e.g., metropolitan, rural, remote) rather than comparing absolute measures of social vulnerability from one location to another at regional and/or national scales.

## Integrated Hazard Threat

Integrated hazard threat is a general measure of who and what are most susceptible to the expected physical impacts of future hazard events. It includes a consideration of both the physical dimensions of threat and the underlying socioeconomic factors within a community or region that may disproportionately limit the capacities of specific population groups to withstand, cope with, and recover from the negative downstream consequences associated with each stage of a disaster.

As illustrated in Figure 4, the severity of hazard threat varies from place to place as a function of (i) geographic setting and exposure to different natural hazard processes; (ii) characteristics of the built environment such as density and patterns of land use that will determine levels of exposure and susceptibility to the expected physical impacts of a hazard event; and (iii) intrinsic characteristics of social vulnerability that have evolved as part of the development process. Our assessment of integrated hazard threat combines measures of social vulnerability (SVI) described above with outputs of a complementary physical exposure model developed by NRCan to measure the susceptibility of buildings, people, and financial assets to known natural hazard processes in Canada

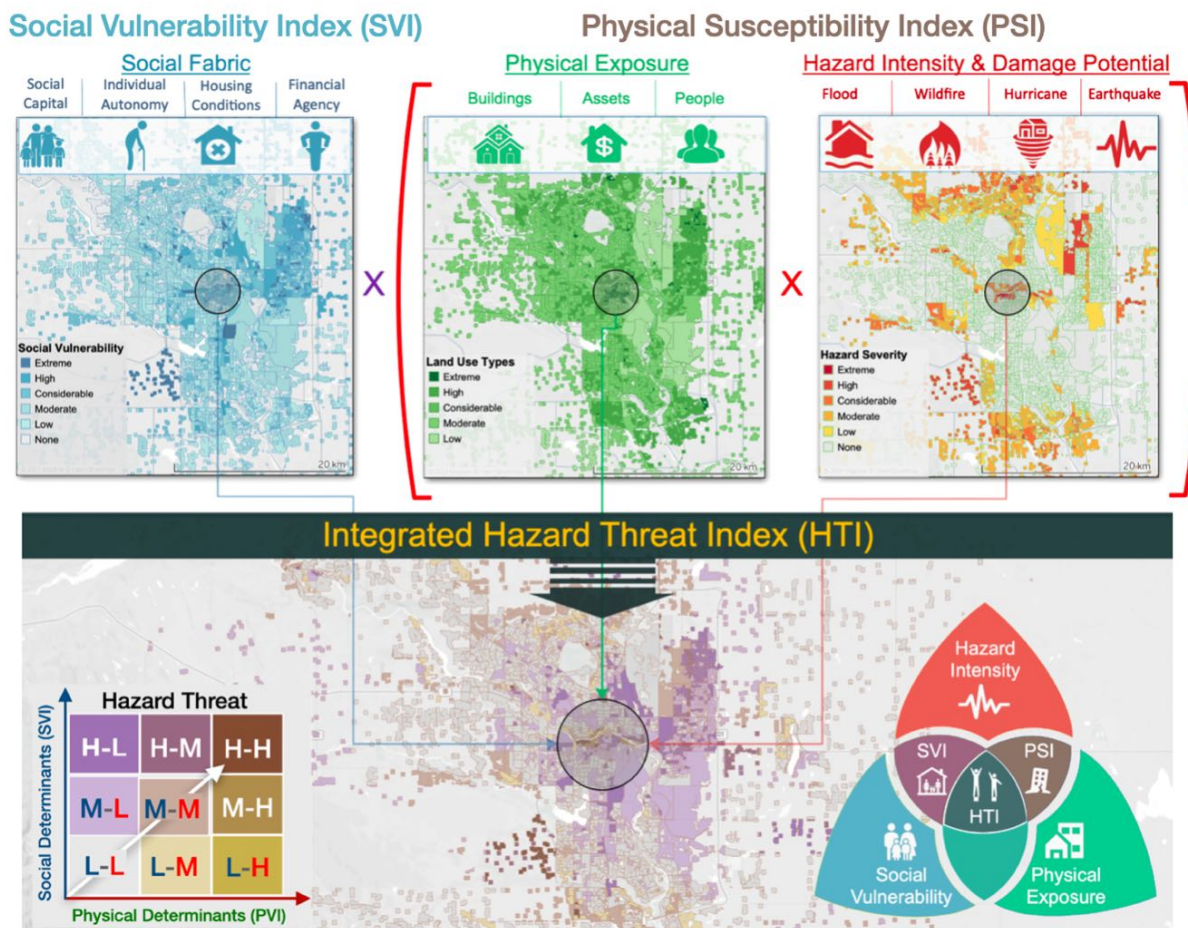


Figure 4: Model components and general workflow for assessing integrated hazard threat in Canada.

(Journeay et al., work in progress, 2022). Perils considered in this broader assessment include extensive natural hazard processes such as earthquakes, tsunamis, hurricanes and wildfire that affect large geographic areas and more intensive flood and landslide hazards that are controlled by local variations in topography and land cover.

Physical dimensions of hazard susceptibility are evaluated using published hazard models for Canada and disaster impact scales that relate measures of hazard intensity to expected levels of physical damage and socioeconomic disruption. Hazard intensities are derived from quantitative models that measure the likelihood of exceeding minimum thresholds of ground shaking, flood inundation, wildfire intensity, and/or hurricane winds at a given location over a specified future time horizon. These include national-level models developed by NRCan for earthquake and wildfire hazards, and open-source global models developed by various international organizations for earthquake-triggered tsunami, riverine flood, and hurricane hazards (Alexander et al., 1996; Løvholt et al., 2015; Rudari et al., 2015; United Nations Global Risk Data Platform 2015; Dottori et al., 2016; Adams et al., 2019; Kolaj et al., 2020). Hazard footprints for each of these perils are intersected with built-up areas of human settlement to assess mean hazard intensity, and the corresponding number of people, buildings, and value of financial assets that are susceptible to corresponding levels of damage (i.e. very low, low, moderate, considerable, high, and extreme).

## KEY FINDINGS AND INSIGHTS

There is an inherent organizational structure to human settlements that varies with geographic setting, population size, characteristics of the built environment, and corresponding levels of hierarchy within broader social, economic, and political systems that define a region or country (Alexander et al., 1977; Clifton et al., 2008; Marshall and Gong 2009). We use these place-based organizational structures and corresponding patterns of development as the context for assessing both fundamental characteristics of social vulnerability that exist at the community level, and underlying factors that may influence the capacities of specific population groups to withstand, cope with, and recover from the impacts and consequences of future disaster events. In particular, we find that settlement type and related patterns of land use provide an effective lens for evaluating social vulnerability in the context of natural hazard threat. Both reflect development histories and related social, economic, and political factors that influence where people live in a community or region, their physical susceptibility to natural hazard threats, and the differential capacities of different population groups to weather the impacts and consequences of future disaster events.

### Intrinsic Patterns of Social Vulnerability in Canada

**Metropolitan Regions.** Along with significant changes to the built environment, the history of urbanization in Canada has also led to more complex patterns of land use, a greater degree of racial and ethnic diversity, and higher levels of disparity within underlying social and economic systems. Although levels of disparity are highly variable from place to place, results of our assessment show that people living in dense metropolitan regions are more likely to experience underlying socioeconomic conditions that can increase disaster vulnerabilities compared with those living in remote rural communities. As illustrated in Figure 5, mean vulnerability threshold scores are relatively high for multi-family residential and mixed-use neighbourhoods in dense urban cores (SAC-1), and steadily increase in surrounding suburban (SAC-2) and exurban fringe areas (SAC-3) that are situated along the interface with surrounding rural areas. Metropolitan regions with threshold scores above national average values occur in southwest British Columbia, Alberta, Quebec and larger population centres in the Yukon and Northwest Territories. Underlying factors that contribute to observed trends in social vulnerability include higher concentrations of people who have either recently moved or immigrated into the region, higher concentrations of people living in unsuitable housing conditions and/or areas with higher levels of commercial activity, and increased economic stresses related to high shelter costs and unstable employment. Additional factors that influence patterns of vulnerability in suburban and exurban neighbourhoods include a greater reliance on public transit to support day-to-day activities, and a diversity of financial stresses for those households living on a fixed income and/or spending more than 30% on shelter costs.

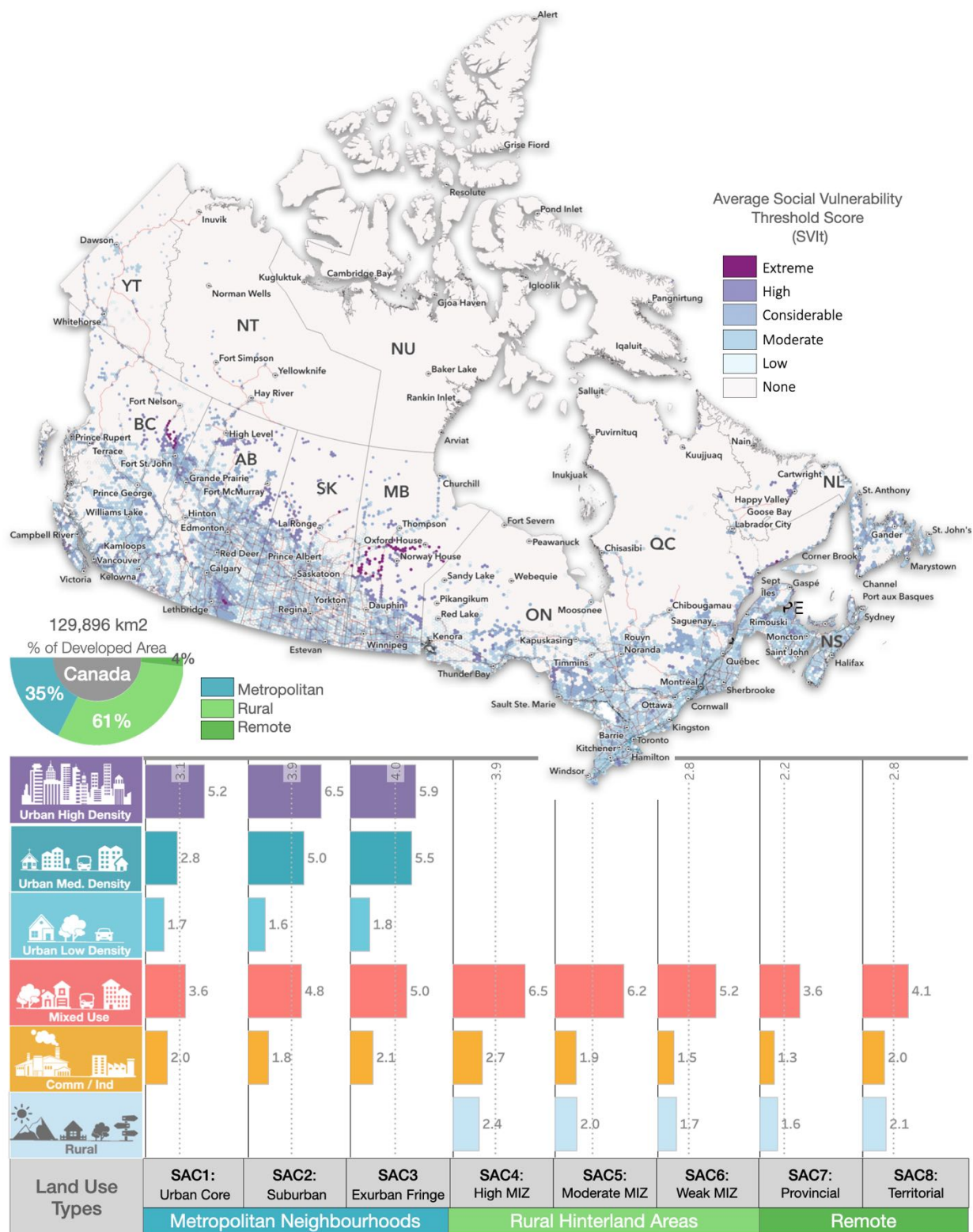
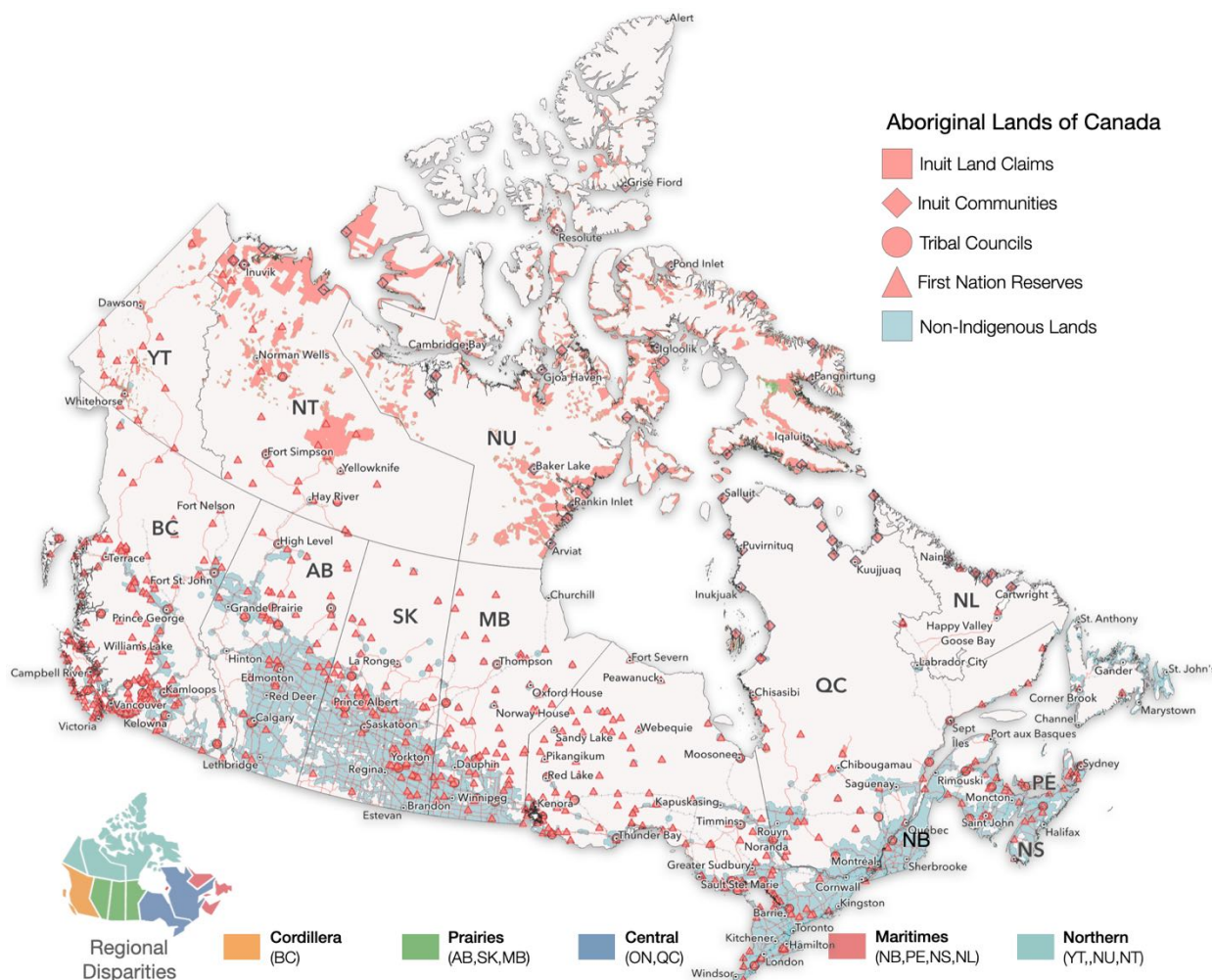


Figure 5: Spatial patterns of social vulnerability and corresponding profiles of mean threshold exceedance score for settlement types within each major physiographic region of Canada. Note that profiles of social vulnerability are referenced to a specific settlement type and should not be compared across settlement types.





			Cordillera	Prairies	Central	Maritimes	Northern Canada
Metropolitan	Urban SAC-1	Prov/Terr Lands	2.7	2.3	2.0	1.5	Land Governance Provincial/Territorial Aboriginal Lands
		Indigenous Lands	2.7	5.1	2.4	2.4	
	SubUrban SAC-2	Prov/Terr Lands	1.8	2.5	1.4	1.1	
		Indigenous Lands	2.8	6.1	3.3	2.9	
	ExUrban SAC-3	Prov/Terr Lands	2.5	2.2	1.7	1.6	3.1
		Indigenous Lands	3.3	3.4	3.7	3.5	2.6
Rural	High MIZ SAC-4	Prov/Terr Lands	3.0	2.5	2.2	2.5	
		Indigenous Lands	3.6	4.0	2.3	2.6	
	Mod. MIZ SAC-5	Prov/Terr Lands	2.8	2.0	1.7	1.8	
		Indigenous Lands	3.3	5.0	2.9	4.0	
	Low MIZ SAC-6	Prov/Terr Lands	1.9	1.6	1.6	1.6	
		Indigenous Lands	2.9	4.8	3.4	3.8	
Remote	Province SAC-7	Prov/Terr Lands	1.7	1.2	1.9	2.5	
		Indigenous Lands	3.3	4.2	2.9	2.7	
	Territory SAC-8	Prov/Terr Lands					2.2
		Indigenous Lands					2.1

Figure 6: Spatial distribution of Indigenous lands and corresponding measures of disparity within settlement types for major physiographic regions in Canada. Disparities are measured based on mean social vulnerability threshold scores. Note that profiles of social vulnerability are referenced to a specific settlement type and should not be compared across settlement types.

**Rural Hinterland.** The areas surrounding major population centres in southern regions of Canada are characterized by a distributed network of smaller cities, towns, villages and clusters of buildings situated within broad agricultural landscapes and/or wildland areas. Activities in these regions support primary food production, resource development, and supply chain logistics that facilitate the transport of goods into neighbouring commercial hubs along an integrated system of roads and rail lines. In contrast to metropolitan regions, rural communities have experienced reduced rates of growth and development over the last forty years caused by younger residents moving to other parts of the country in search of employment and economic security (Chagnon et al., 2019). As illustrated in Figure 5, mean vulnerability threshold scores are elevated in rural areas immediately surrounding larger population centres in which there are higher degrees of dependence on social and economic services (SAC-4) and generally decrease with distance away from major metropolitan regions (SAC-5 and SAC-6).

These general trends are mirrored in all regions of Canada with mean vulnerability threshold scores above national average values for rural areas with high metropolitan influence and below national average values for more remote rural areas with weak levels of metropolitan influence. Mean vulnerability threshold scores are highest in mixed-use residential and commercial areas that occur primarily in the downtown areas of smaller cities and towns, and along major transportation corridors (see Figure 5). Underlying factors that contribute to observed trends include a higher overall proportion of the population with no fixed workplace, less stable employment, lower levels of secondary education and a higher concentration of lone parent families with young children. Additional factors that influence patterns of disparity include housing stresses caused by higher concentrations of people living in older buildings of poor construction, accommodations that are considered unsuitable for the number of occupants, and financial stresses associated with households who rely on a single income or spend more than 30% on shelter costs.

**Remote Settlements.** Remote regions of Canada include sparse settlements along the coastline in western British Columbia and the eastern Maritime provinces; isolated regions in the Interior Prairies of Saskatchewan and Alberta; boreal forest regions of the Yukon and Northwest Territories; and broad regions of the arctic in Nunavut. These are regions in which there is negligible socioeconomic influence from metropolitan regions and a greater focus on sustainable land use practices based on fishing, trapping, and subsistence hunting. People living in these areas may have limited or no direct connection with established critical infrastructure systems (transportation, water, and energy) and often must travel to neighbouring regions to access health care and other essential services. Mean vulnerability threshold scores are generally above national average values for larger population centres of the North (SAC-3) in which there are higher concentration of mixed-use residential and commercial lands; and below average values for lower-density rural residential areas that occur in smaller villages, hamlets, and isolated settlements. The exception is in more remote regions of Nunavut, where mean vulnerability threshold scores are above average values when compared with equivalent low-density residential regions of the Yukon and Northwest Territories. Underlying factors that contribute to elevated levels of vulnerability in these areas include reduced levels of individual autonomy related to concentrations of Indigenous Peoples living in larger towns and cities with more limited connections to traditional territories, unreliable access to health care and essential services, unstable employment and related financial stresses, overcrowded housing and higher concentrations of buildings constructed prior to the introduction of modern safety design guidelines.

### Disparities Related to Land Governance

Place-based statistical profiles provide important insights on how patterns of social vulnerability vary for each settlement type as a function of physiographic setting and characteristics of the built environment (i.e., density and functional land use). However, they do not fully explain more localized patterns of socioeconomic disparity related to land title and associated land governance systems that exist between Indigenous communities and the general population. These disparities are well known and have been the focus of ongoing efforts to measure gaps in well-being and monitor the effectiveness of strategies that have been implemented to address underlying factors of inequity and marginalization that exist within many Indigenous communities across Canada (Matheson et al., 2012; O'Sullivan 2013; Auditor General of Canada 2018; Indigenous Services Canada 2019;

Statistics Canada 2019; Chakraborty et al., 2021). Results of our assessment (see Figure 6) provide an opportunity to evaluate these differences in more detail through the lens of broad settlement types and associated characteristics of land use that influence the ways in which patterns of social vulnerability are manifest at the community level.

The focus of our assessment is primarily on understanding localized patterns of disparity within a given region and identifying contributing factors that are relevant in the context of managing disaster risk rather than measuring absolute levels of social vulnerability or comparing index values between different communities. We acknowledge that metrics designed to measure levels of social vulnerability for non-indigenous communities are based on North American cultural norms and may not be appropriate for assessing comparable levels of vulnerability for Indigenous communities; particularly those who have retained a strong connection to ancestral values, family structures, traditional forms of knowledge, and land-based sources of livelihood (Guthro 2021). Nonetheless, census-based demographic variables are effective in providing a systematic description of social fabric for all regions in Canada and can be useful in identifying underlying factors that may differentially affect the capacity of community members to manage the impacts of a hazard event based on characteristics of tenure and associated land management systems (i.e., governance). These insights can help inform emergency planning and strategies that promote broader objectives of disaster resilience and sustainable development at the community level.

Differences in measured levels of social vulnerability between those living on Indigenous lands and those of the broader population are most pronounced in the Interior Prairie provinces of Alberta, Saskatchewan, and Manitoba. Relative degrees of variance in the southern part of the Prairies range between a factor of 1.5 and 2.4 for more densely settled metropolitan regions and increase to a factor of ~3.5 for more remote settlements that have little or no socioeconomic integration with neighboring population centres. Patterns of disparity are less extreme in Central and Maritime regions where relative degrees of variance range between 1.2 and 2.6 for more densely settled metropolitan regions, and from 1.1 to 1.5 in more remote settlements of northern Quebec and Labrador. Although still significant, patterns of disparity are more subdued in the Cordillera and Northern regions of Canada. Differences in mean levels of vulnerability are negligible in the major urban centres of southwestern British Columbia but increase in more rural and remote settings where measures of vulnerability for Indigenous communities exceed those of the general population by a factor of between 1.3 and 1.9. These patterns are reversed in the North, where levels of disparity for people living on Indigenous lands are lower than for those of the general population living under provincial jurisdiction in larger population centres

## Disasters by Design

Disasters are the predictable outcome of ongoing growth and development in areas where both physical systems of the built environment, and the complex network of interconnected social, economic, and political systems that define the essential fabric of cities, towns, and rural communities are periodically overwhelmed by the forces associated with natural hazard events (Burby 1998; Kunreuther and Roth Sr 1998; Mileti 1999; Cutter 2001; Tierney et al., 2001). If so, why is it that the most vulnerable members of society continue to be situated in areas that are both more susceptible to the physical impacts of future disaster events and disproportionately affected by land governance decisions that limit their capacity to weather the downstream socioeconomic consequences? May and Deyle (1998) suggest the answer to this thorny question may lie at the intersection of conflicted public policy agendas where common good goals of public safety, economic security, social equity, and environmental justice are systematically overshadowed by the more immediate concerns of promoting growth and maximizing the shorter-term economic benefits of developing privately owned lands at the community level.

Although not surprising, the results of our assessment of earthquake-related hazard threats in Canada are consistent with other studies that document higher intrinsic levels of social vulnerability in areas that are more highly susceptible to the both the immediate physical impacts and negative downstream consequences of future disaster events (e.g., Cutter et al., 2003; Burby 2006; Burton et al., 2018; Global Earthquake Model Foundation [GEM] 2020). Disparities in the relative level of physical susceptibility to seismic hazards vary from place to place as a function of local geological conditions that result in the amplification of ground shaking intensities,



variations in topographic relief that affect tsunami wave heights and the severity of inundation in communities situated along isolated coastlines, and anomalous levels of social vulnerability related to the history of development and related patterns of land use. However, the cumulative effects of land use decisions that determine where people live in each community or region appear to have the most significant influence on observed patterns of natural hazard threat.

As it turns out, centres of commerce established early in the history of colonial settlement which have since become the hubs of major urban growth and development are situated in active tectonic regions that are susceptible to some of the most severe earthquake and tsunami hazards in Canada. Areas of greatest concern include high-density urban centres with concentrated patterns of mixed residential and commercial land use in which intrinsic levels of social vulnerability are ~68% above mean values for surrounding regions; and rural/remote communities exposed to the combined effects of earthquake ground shaking and tsunami inundation where less structured frameworks of land management result in higher levels of intrinsic social vulnerability. Based on preliminary model outputs, we estimate that nearly one in six Canadians (~5.8 million people; 16.5% of total) live in areas of the country where community members are least able to withstand and cope with the negative impacts of future earthquake and/or tsunami disasters (see Figure 7).

More than half of all those affected by earthquake-related hazards capable of causing significant structural damage (56%) are situated in more densely settled areas of the St. Lawrence Lowland in southern Quebec and eastern Ontario with an additional 41% of the population concentrated in areas of higher overall threat along the west coast of British Columbia. The New Brunswick region of the Eastern Maritimes contributes another ~3% to the overall national profile of hazard threat while more remote settlements in the Yukon, Northwest Territories, and Nunavut represent ~0.2% of the total. In Western Canada and the North, we find that mean hazard threat scores for those living on Indigenous lands exceed average values for the rest of the population by ~12%. Although fewer people are affected overall, mean levels of hazard threat are higher than in other parts of the country with values in the upper half of the regional distribution for many areas of southwestern British Columbia, the Yukon, Nunavut, and Northwest Territories.

While there is an obvious need to measure the potential physical impacts of natural hazards and how they vary from one location to another, it is equally important to understand who is in harm's way, cultural perceptions of risk, and potential issues of social inequity that may be associated with the spatial distribution of hazard threats within a given community or region. The integration of social and physical dimensions of hazard threat provides important insights on who is likely to bear the greatest burden of risk following a disaster event, the underlying causal factors that systematically disadvantage the most vulnerable in our communities, and strategic opportunities for increasing capacities for functional recovery at the neighbourhood level.

A primary motivation for developing the national social vulnerability model and assessing how associated profiles of disparity are manifest across different settlement types and regional patterns of development is to establish a detailed base of evidence to inform policies that are effective in reducing the lasting negative impacts of future disaster events on the most vulnerable members of a community or region. To this end, we have endeavored to establish methods and results that can be effectively used in practice to measure intrinsic social vulnerabilities and their relationship to local patterns of development. Understanding the combined social and physical determinants of natural hazard threat and the underlying factors that contribute to systemic patterns of inequity at the community level provides a necessary foundation for assessing evolving conditions of risk. It is also an important first step in identifying intervention strategies (e.g., capacity development, mitigation, adaptation) that are effective in reducing intrinsic vulnerabilities and promoting the longer-term prospects of disaster resilience and sustainable development in Canada.

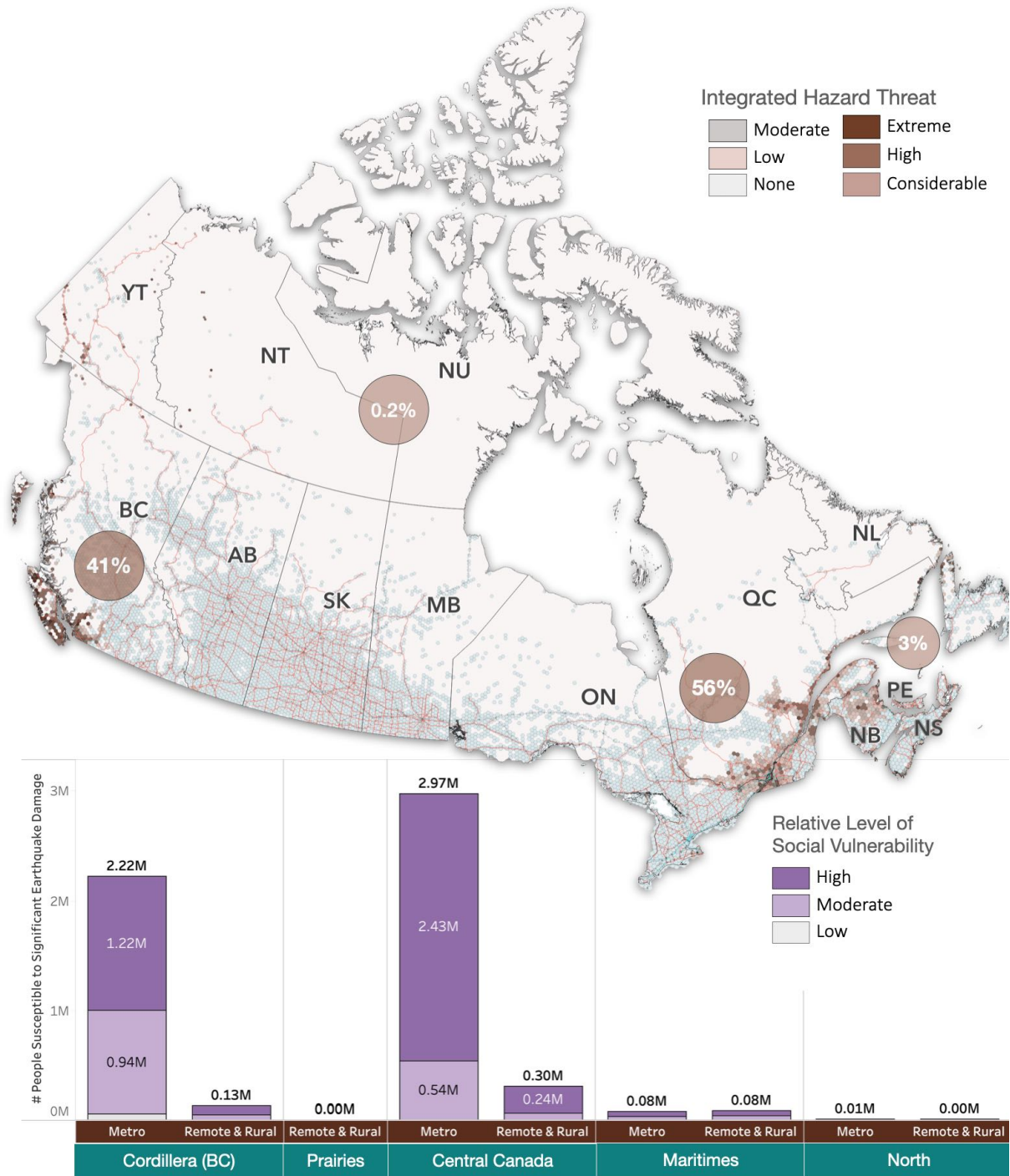


Figure 7: Population affected by significant earthquake and tsunami hazard threats in Canada. Charts summarize exposure by relative level of social vulnerability

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